On the Contribution of Remote Sensing to DOPA, a Digital Observatory for Protected Areas.

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Abstract – The Digital Observatory for Protected Areas (DOPA) is a biodiversity information system currently developed as a set of interoperable web services at the Joint Research Centre of the European Commission in collaboration with other international organizations, including GBIF, UNEP-WCMC, Birdlife International and RSPB. DOPA is not only designed to assess the state and pressure of Protected Areas (PAs) and to prioritize them accordingly, in order to support decision making and fund allocation processes, but it is also conceived as a monitoring and modelling service. To capture the dynamics of spatio-temporal changes in habitats and anthropogenic pressure on PAs, the automatic collection and processing of remote sensing data are at the heart of the system. The purpose of this paper is to highlight the variety of uses of remote sensing data by the DOPA, the integration with other data sources, the practical implementation according to an architecture grounded in international initiatives such as GEOSS, GSDI and INSPIRE, and applications in monitoring and ecological modelling.

Keywords: SOA, biodiversity, protected areas, GEO-BON, remote sensing, Web Services

1. INTRODUCTION

Biodiversity loss is a key 21st century challenge and protected areas are a vital part of the response. Effective protected area management deals with complex links between environmental and anthropogenic factors, calling for information gathered from many disciplines. The information needs range from molecular to global scales and cover time periods from hours to centuries. This multidisciplinary aspect has resulted in the collection and independent maintenance of large data volumes, and developed models are often operated in isolation. The use of Service Oriented Architecture (SOA) based on distributed computing technology is revolutionizing the way we deal with information. Moreover, international initiatives, such as the Group on Earth Observations (GEO), encourage different communities to make their systems and applications interoperable. The Digital Observatory for Protected Areas (DOPA) specifically targets the challenges of multi-scale, cross-disciplinary science for biodiversity protection. The DOPA is in development at the Joint Research Centre of the European Commission in collaboration with other international organizations, currently including the Global Biodiversity Information Facility (GBIF), the UNEP-World Conservation Monitoring Centre (WCMC), Birdlife International and the Royal Society for the Protection of Birds (RSPB). It is conceived as a set of distributed databases and open, interoperable web services to provide decision makers and researchers with means to assess, monitor and forecast the state and pressure of protected areas (PAs) at the global scale. Data on PAs, species distributions, socio-economic indicators are therefore combined with remote sensing information to generate objective global environmental indicators, maps and alerts. Figure 1 summarises a typical process in which data are collected from various sources, and processed for further integration with other data before the publication of new information.

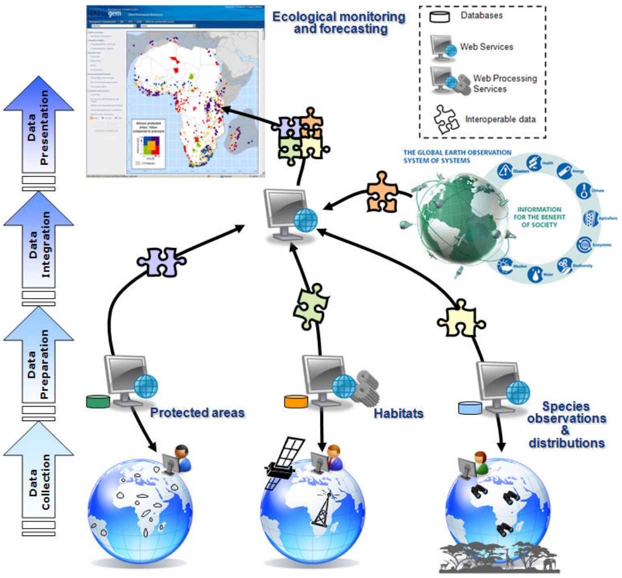

Figure 1. From ground based and remote sensing observations to environmental indicators: data need to be collected, processed to allow their combined use, and integrated to prepare ecological maps and indicators.

2. DOPA AND GEO-BON: THE IMPORTANCE OF AN INTEROPERABLE ARCHITECTURE

As for most environmental information systems, the main challenge in setting up the DOPA comes from the handling of a large variety of data types and sources. Hartley et al. (2007) provide a description of a first prototype of the DOPA focusing on Africa - the African Protected Areas Assessment Tool (APAAT). The APAAT was designed to provide decision makers with a tool to assess the state of PAs in Africa and to prioritize them according to biodiversity values and threats, so as to support decision making and fund allocation processes. In order to evolve towards a proper operational environmental monitoring and forecasting service, the system needed to be able to capture more regularly the spatio-temporal environmental changes, implying that new means had to be put in place to ensure the automatic update of the information presented. In particular, the development of tools for biodiversity monitoring and forecasting requires some significant changes in the way data are collected and processed (Dubois et al., 2009). Important efforts have already been made at the Ecological Forecasting lab at NASA Ames Research Center where a Terrestrial Observation and Prediction System (TOPS) has been setup to develop nowcasts and forecasts of ecosystem conditions for use in a range of applications (Nemani et al., 2009). TOPS is a data and modelling system designed to integrate data from satellite, aircraft, and in situ sensors with weather/climate and application models to produce nowcasts and forecasts of ecological conditions. Although sharing a number of similar objectives with TOPS, the DOPA is relying mainly on distributed databases managed by the collaborating organisations and on open, interoperable web services. These web services are relatively basic for the time being given the need to start from a set of operational systems that can be easily interlinked. Still, the simplified design of data exchange, as shown in Figure 1, becomes very complex in the absence of syntactic and semantic interoperability of the data and the systems serving them. This is a well known issue that was addressed by the Biodiversity Observation Network of the intergovernmental Group on Earth Observations (GEO-BON), which is leading the integration process of biodiversity data via Service Oriented Architectures (SOA

3. THE eSTATION, DOPA'S NEAR REAL-TIME REMOTE SENSING MONITORING SYSTEM

Because the DOPA is targeting mainly regional and global biodiversity issues, spatio-temporal changes in habitats and anthropogenic pressure on PAs and other areas of ecological importance need to be captured as much as possible automatically and on a large scale. This requirement is primarily addressed via the widespread use of remote sensing data, which is a key component of the system. The DOPA therefore partly relies on the eStation, a collecting and processing system developed by the JRC in the frame of the FP7 Geoland2 project and in support to the AMESD initiative (African Monitoring of the Environment for Sustainable Development, see http://www.amesd.org). The eStation is the component of AMESD dealing with the reception, processing, analysis and dissemination of key environmental parameters. The eStation automatically retrieves remotely sensed data, derived from the measurements done by the SPOT/VGT, SEVIRI/MSG and TERRA-AQUA/MODIS Earth Observation systems, and computes ad-hoc thematic products and environmental indicators, according to the end-user needs. All processing steps are easily configurable allowing the user to modify the generated environmental indicators and to implement new ones.

3.1 Detecting environmental anomalies

In the DOPA, environmental anomalies are detected in protected areas by contrasting every 10 days the current records of environmental data against historical records (Figure 2). The parameters currently analysed include rainfall, active fires, small water body presence, and two vegetation indices: the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI). The system has also been developed as an experimental early warning system to detect environmental anomalies in the PAs. Every ten days (dekads), the measurements are automatically compared against seasonal norms and alerts can be issued. These anomalies can be characterised by their strength, their duration and their deviation from their expected occurrence in time, something typical of seasonal changes.

• The *strength* of the alert represents how different it is from the expected value. The bigger the difference, the greater the strength.

• The *deviation* of the alert tries to determine if the alert may simply be an early or late event such as an early start to the rainy season or a late start to the fire season. We search through the historical data to see if a similar event has ever occurred within a few dekads either side of this date. The larger the time window with no such similar historical event the greater the deviation.

• The *duration* is simply the number of dekads over which the anomaly has been ob-served; 1, 2, 3 or more dekads.

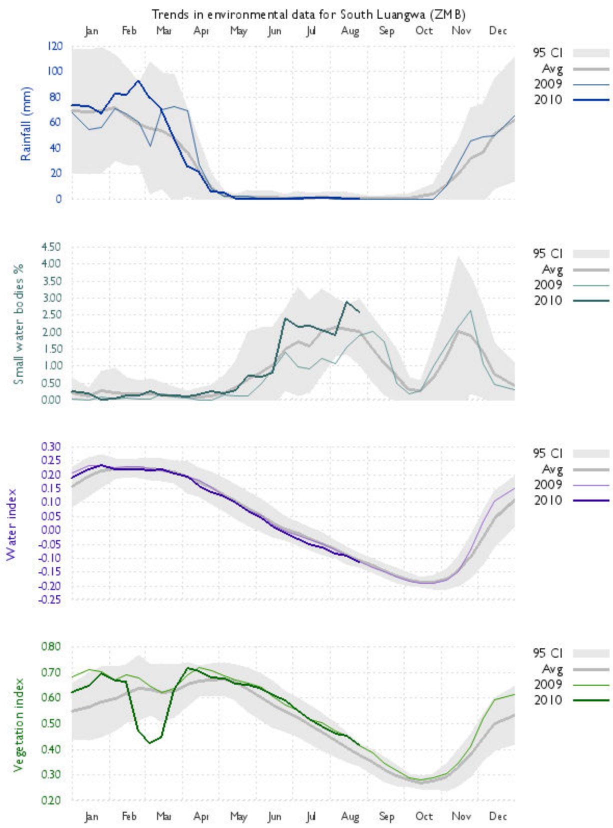

Figure 2: Dekadal behaviour (situation on 20/08/2010) of environmental factors (rainfall, small water bodies, vegetation indices: NDWI, NDVI) observed in the South Luangwa NP (Zambia) plotted against the averaged data of the previous year and longer term trends. Dark gray lines are the average for each dekad based on the available time series. Light grey areas indicate the 95% confidence limits around these averages.

Detected anomalies can then be sent automatically to end-users who are subscribed to the RSS feeds which serve as an early warning system. See Hartley et al. (2007) and Carrara et al. (2008) for more details on this alert system. In addition to this near real-time monitoring activity, a longer term approach is foreseen which will possibly allow the forecasting of the impact of the main threats to biodiversity, namely habitat degradation and climate change.
The next chapters will briefly review the main ecological variables monitored by the DOPA.

3.2 Monitoring vegetation

The VEGETATION instruments onboard the SPOT satellites allow the production of 10-day global coverage composites at 1 km resolution. In the framework of the FP6 Specific Support Action VGT4Africa, VEGETATION data covering Africa are used to generate a series of products related to the monitoring of vegetation and surface water. The products are broadcasted to the EUMETCast receiving stations installed in Africa, making African land surface monitoring available automatically at no charge for the users. The time series of NDVI data allows identification of changes in vegetation vigor and density in response to bio-physical conditions (including plant type, weather and soil) and human activities. NDWI (Gao, 1996) is rather related to the vegetation water content (Ceccato et al., 2002) and presents some advantages in the usually cloudy equatorial areas due to the low sensitivity of the index to atmospheric conditions in comparison to the NDVI (Xiao et al., 2003, Vancutsem et al. 2009).

3.3. Water & Small Water Bodies

The same VEGETATION instrument allows the detection of surface water, thanks to its short wave infrared channel, at the resolution of 1 pixel (1 km). The continuity of surface observation allows the seasonal assessment of water availability. Monitoring the surface water availability means interpreting the temporal sequence of availability of ephemeral and temporary water surfaces detected by the SPOT-VEGETATION system. A long time series of data (from 1999 to 2007) has been used to characterize the type of water bodies, i.e. permanent or seasonal as well as their recurrence and the maximal extent of surface water. The seasonal integration characterizes the annual water availability and the date of availability (see e.g. Figure 3)

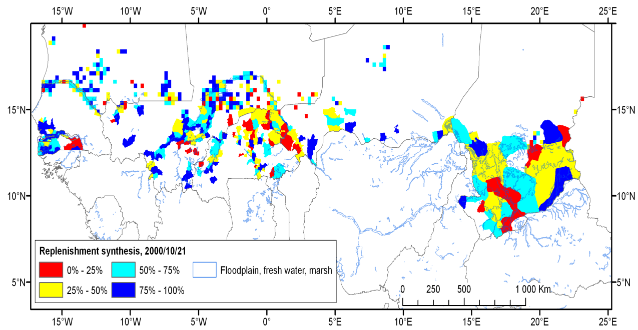

Figure 3: Example of a small water body product. The map shows a synthesis of the replenishment process on 21 October 2010 in Western Africa.

The small water bodies product consists in the detection of the surface water, at full satellite resolution (1 km) every 10 days, in three classes: free water, humid area and a mixture of both. The free surface water detection has been successfully validated on western Africa with a commission error lower than 2% for free water detection. Former analysis have shown that the system is able to detect temporary water bodies that are often not reference in other data bases, such as GLWD (Lehner et al, 2004). In addition to the mapping of water pixels in water, the product has also time components, namely the start of replenishment of the small water bodies in the season and the end of availability of these water bodies and the duration of their detection

Monitoring surface water scattered in small water bodies provides useful information for several applications, including human activities, cattle management, epidemiology, biodiversity (incl. migrating birds). In addition long term time series of water occurrence in semi arid regions is an interesting indicator of the impact of climate variation (Combal et al., 2009). The products should not be considered highly accurate for water body mapping because of resolution. Nevertheless indication about seasonal behaviour of few water bodies in a given region should allow extrapolation of conditions to smaller water bodies.

3.4 Fire ecology

Fire is a crucial ecological component of many ecosystems, especially in the savannas where it contributes to maintain the habitat over time, keeping the balance between the herbaceous and woody vegetation. Savannas cover large regions in Africa and this is also the main reason for the high fire activity in this continent, which registers among the highest fire occurrence rates in the world. Since fire is so wide spread in Africa many plant and animal species have evolved with it and are now dependent on its occurrence. For these reasons in many conservation programs fire becomes an essential element to promote biodiversity and support land management. The JRC is therefore monitoring fire activity in sub-Saharan PAs using MODIS fire products available through the NASA funded Fire Information for Resource Management System (FIRMS). Information on fire occurrence is derived four times a day by the MODIS sensors onboard the TERRA and AQUA satellites. Active fires data are available with a 1km spatial resolution, while the information on the burned areas extent is provided at 500x500 m resolution. The data are used to characterize the spatial and temporal distribution of fires but also to define the fire intensity using the Fire Radiative Power (FRP) provided by the MODIS active fire product. Monitoring the fire activity through different levels of information like the fire occurrence (timing and frequency), the burned areas extent and the FRP allows a more complete understanding of the phenomenon. In addition 25km buffer zones surrounding the PAs are included in the analyses on the fire occurrences to assess external threats and pressures (Palumbo et al., *in prep*.). The possibility to derive information on the fire intensity will improve our capacity to predict the effects of fire on vegetation and the habitat. This has also important implications for the biodiversity and can support park managers and policy makers in their future plans and actions.

3.5 The Land Surface Temperature

The Land Surface Temperature (LST) is the radiative skin temperature over land. It plays an important role in the physics of land surface as it is involved in the processes of energy and water exchange with the atmosphere. LST values are of special interest for meteorology, hydrology, agrometeorology, climatology and environmental studies. The LST product is distributed at the original MSG repeat cycle (15 minutes), and averaged over 1 day and 10 days periods routinely computed.

3.6 Rainfall

Rainfall is one of the most important part of the water resource. Due to financial and infrastructural constraints, rain-gauge and precipitation radar networks are currently extremely sparse over most of Africa. There is a particular shortage of rain-gauge data that is available in real time. For such areas the satellite rainfall estimate is a good alternative to overcome the shortcomings of measurements. Three source of satellite rainfall estimate are used in the framework of this project: FEWSNET Rain Fall Estimate (RFE), TAMSAT RFE and the near real-time 15 minutes Multi-sensor Precipitation Estimate from EUMETSAT.

4. REMOTE SENSING FOR LONG TERM ASSESSMENTS

The 10th Meeting of the Conference of the Parties (COP10) of the Convention for Biological Diversity (CBD), held in October 2010, led to the adoption of the Nagoya Protocol and the establishment of 20 Aichi Targets to prevent biodiversity loss. One of the goals is to expand the global PA network as biodiversity protection zones from 10 percent to 17 percent for terrestrial and inland water areas, and from 1 percent to 10 percent for coastal and marine areas. These plans represent a huge challenge given the rapid population growth and the resulting constant stimulation of the competition for land and natural resources. More than ever, there is the need to monitor PAs and beyond. Human disturbances such as settlements, agriculture, livestock grazing and logging expand often right up to the PAs boundaries. Ecological corridors, which are essential to sustain the connectivity between PAs, often lack formal protection. It gives way to human activities that sometimes lead to high fragmentation rates compromising the functionality of the corridors. Moreover, human disturbances have also been frequently reported to be found inside the parks. At a global scale, the monitoring of land cover in and around PAs provides effective means to assess the vitality of the protected habitat and its integration in the ecological system. Furthermore, detected changes between successive observations give indications of disturbances. Combined with additional biophysical and socio-economic information, they can help to understand the nature and dynamics of the anthropogenic threat that has led to the land cover change.

To address land cover changes, DOPA currently relies on the MODIS Land Cover product at 500 m spatial resolution. Between 2001 and 2008, the MODIS land cover discipline group has produced annual classifications, each one based on one year MODIS input data. Changes are analysed using the classifications from 2001 and 2008 to assess the rates and types of land cover change in PAs and their surroundings. In the future, observation period will be extended till the 1970's using other data sources to give then also indications about the long-term dynamics of land cover change.

Anthropogenic threats are also currently captured mainly through the processing of remote sensing information used. DOPA calculates agricultural pressure, population density and habitat fragmentation indicators for the areas surrounding PAs to assess pressures on the protected habitat.

5. CONCLUSIONS AND FORTHCOMING DEVELOPMENTS

To capture the dynamics of spatio-temporal changes in habitats and anthropogenic pressure on PAs, the automatic collection and processing of remote sensing data are core functions of the system. Both the DOPA and the eStation are completely based on OpenSource software and on an architecture of open standards and specifications. It is therefore a flexible and cost-effective platform for the implementation of information services needed for environmental and natural resources policy orientation, management and assessment, in different thematic areas, like the monitoring of natural vegetation, agricultural production, water resources, coastal and marine regions. Ongoing short and long term efforts are currently focusing on extending our applications to the marine environment and on making our remote sensing information available online with the help of catalogues and to publish the eStation as a web service to be potentially consumed by other environmental services. It is becoming increasing important to provide efficient means to publish and discover information resources though interoperable catalogues and search mechanisms, including tools such as brokers which can handle semantic differences across multi-lingual and multi-disciplinary boundaries. In parallel to DOPA, an extensive catalogue is being developed and published as a web service, using the relevant specifications endorsed by the Global Earth Observation System of Systems (GEOSS), and addressing longer term issues such as semantic interoperability is a focus of the EuroGEOSS project.

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